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Original article

45°-45°-30°Frog-leg radiograph for diagnosing cam-type anterior femoroacetabular impingement: Reproducibility and thresholds☆

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ABSTRACT

Background: The many radiographic views suggested for evaluating anterior femoroacetabular impingement (FAI), due to a cam effect, are not specific for this condition and have not been proven of diagnostic value in studies, including control groups. Using a new and specific radiographic view, we evaluated the reproducibility of the main radiographic criteria for FAI, determined normal values for these criteria in a control group, and established diagnostic threshold values.
Hypothesis: This specific view offers good reproducibility and effectively detects abnormal values of criteria for FAI.
Materials and methods: Inter-observer and intra-observer reproducibility of specific radiographic criteria (α angle and modified head-neck offset [HNO]) were computed from preoperative and postoperative radiographs of 96 hips (75 patients, 61 males and 14 females) using the specific 45°-45°-30° frog-leg view (F45 view). Values in the group with FAI were compared to those in a control group of asymptomatic volunteers (100 hips, 27 males and 23 females).
Results: Inter-observer and intra-observer reproducibility was very good, with intra-class correlation coefficients of 0.955and 0.987, respectively, for the α angle and of 0.895 and 0.984, respectively, for the HNO. Mean values of both parameters differed significantly between the FAI and control groups: 73.9° (53° to 96°) vs. 49.3° (35° to 69°) for the αangle, respectively; and 2.5 mm (–4.6 to 9.4) vs. 7.6 mm (1.7 to 11.8) for HNO, respectively. The normal values defined as the boundary of the 95% reference interval in the control group were < 60.2° for the α angle, and > 4.6 mm for the HNO.
Discussion: The45°-45°-30° frog-leg view is useful for diagnosing FAI due to a cam effect. This view is easy to perform, and the thresholds determined in our study assist in its interpretation: α angle values > 58° in females and > 63° in males indicate cam-type femoral geometry. In both genders, HNO values < 5 mm support a diagnosis of anterior FAI.
Level of evidence: Level III, case-control study.

1. Introduction

The diagnosis of anterior femoroacetabular impingement (FAI) due to a cam effect rests on the radiological analysis of bone abnormalities at the anterior and superior part of the femoral neck [1,2]. To facilitate this analysis, we advocate the use of a specific radiographic view [1,2], the 45°-45°-30° frog-leg view or F45 view, which is an antero-posterior view of the pelvis with the hips in 45° of flexion, 45° of abduction, and 30° of external rotation. This hip position is achieved by positioning the ipsilateral foot in the sagittal plane, on the midline, with the heel slightly distal to the contralateral tibial tuberosity (Fig. 1). The F45 view is used in everyday practice [3]. Experimental data suggest that it may be effective and superior over other views [4], and it has been used in other studies of cam-type FAI [3,5,6].

Here, our objective was to characterise the F45 view by measuring the reproducibility of the main radiographic criteria for FAI, determining normal values of these criteria in a control group of healthy individuals, and establishing threshold values to assist in the diagnosis of cam-type FAI. Our hypothesis was that the specific

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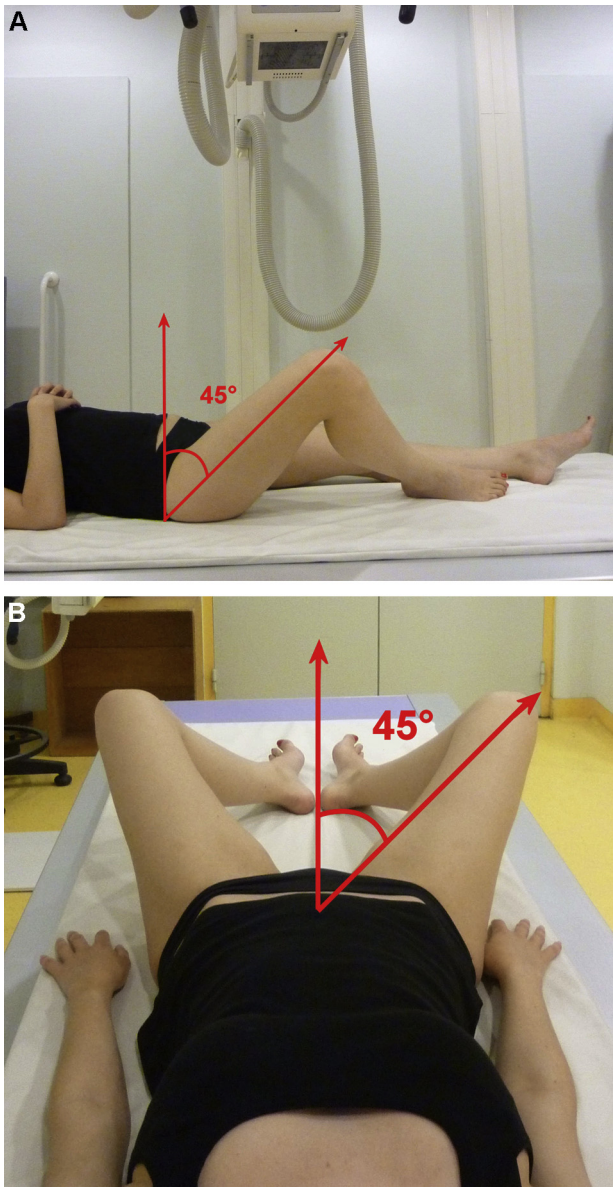

Fig. 1. A. 45°-45°-30° frog-leg view: the patient is supine with the hip flexed at 45°. B. 45°-45°-30° frog-leg view: the hip is in 45° of abduction and 30° of external rotation.

F45 view offers good reproducibility and is effective in detecting abnormal values of criteria for FAI.

2. Material and methods

2.1. Patients

Our study involved two phases. First, we evaluated the inter-observer and intra-observer reproducibility of each radiographic criterion by computing the intra-class correlation coefficients (ICCs). The criteria were assessed on preoperative and postoperative F45 views from patients with cam-type FAI. Then, we determined the values of radiographic FAI criteria in this patient group, as well as their normal values in a control group of healthy individuals, and we used the results to determine threshold values for diagnosing FAI (Fig. 2).

We measured four radiographic criteria, the α angle, the antero-superior head-neck offset (HNO), the antero-superior offset ratio (AOR), and the femoral head radius. We defined the α angle according to Nötzli et al. [7] (Fig. 3). HNO was a variant of the criterion described by Eijer et al. [8]: we drew a line tangent to the femoral head and parallel to the axis of the femoral neck then, measured the distance between this line and a parallel line through the intersection of the antero-superior neck cortex and the circular projection of the acetabular cavity (Fig. 4). This variant was designed to improve reproducibility while being applicable to all neck types and highly relevant, as the projection of the acetabulum allows the femoral neck to be measured at the site of potential abutment against the labrum and acetabular rim. We computed the antero-superior offset ratio (AOR) as the HNO divided by the femoral head diameter to obtain a criterion independent from inter-individual variations in corpulence. Finally, we determined the femoral head radius, both to allow a comparison of the reproducibility of this basic measurement to those of the α angle and HNO and to allow computation of the AOR.

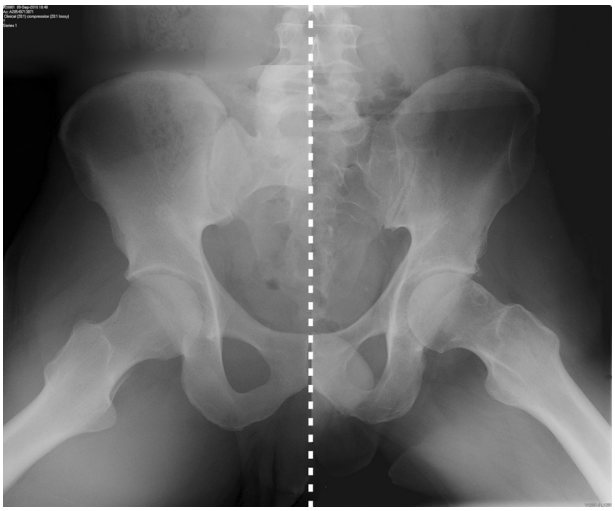

Fig. 2. 45°-45°-30° frog-leg view: normal right hip geometry, cam deformity of the left hip.

The group of patients with FAI included consecutive patients who underwent surgery for FAI diagnosed based on a converging set of clinical and radiological criteria (from radiographs and/or computed tomography [CT] and/or magnetic resonance imaging [MRI]) and for whom preoperative and postoperative F45 views were available. Exclusion criteria were incomplete, poor-quality, or non-digitized radiographs; and pure pincer-type impingement. We identified 125 surgical procedures performed in 99 patients between July 2005 and May 2011. Two patients were lost to follow-up and 27 had missing or non-evaluable radiographs, leaving 96 hips in 75 patients for the study.

The controls were selected among physicians and medical residents at the Toulouse university hospital, using the following inclusion criteria: no history of hip disease or symptoms, willingness to volunteer for the study, and consent to study participation after receiving full information about the risks associated with radiation exposure during the pelvic radiograph obtained for the study. The controls were matched for age and height to the patients with FAI. The control group comprised 100 "normal" hips (Table 1).

2.2. Analysis of the radiographs

The radiographs were analysed using Digimizer™ software v.4.0.0.0 (MedCalc Software, Mariakerke, Belgium). The preoperative and postoperative F45 views in the FAI group were used to determine inter-observer reproducibility (with each criterion determined by three independent observers, AE, XBI, and JM) and

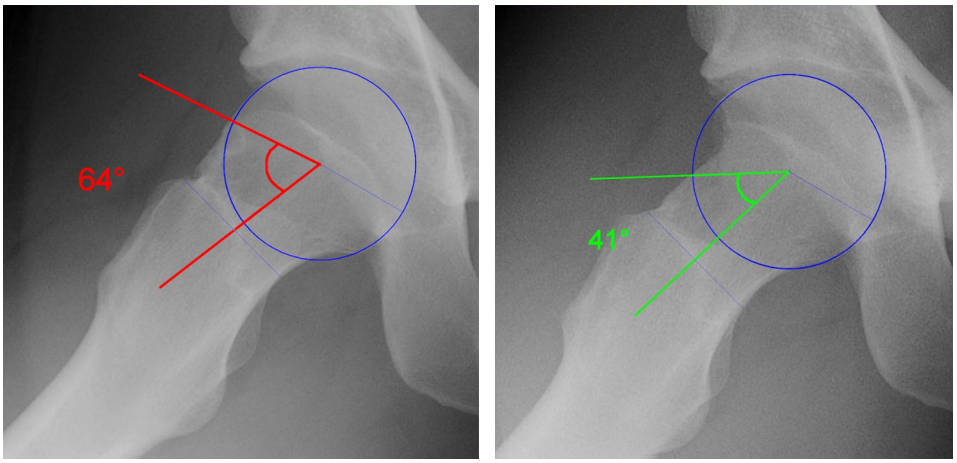

Fig. 3. α angle before (64°) and after (41°) surgery of femoroacetabular impingement.

Table 1
Age and height in the group of patients with cam-type anterior femoroacetabular impingement and control group.

	FAI group	Control group	*P* value
Overall			
Patients–hips *n*	75–96	50–100	
Age, years	38.0 (36.0–40.0)	36.2 (34.0–38.4)	0.205
Height, cm	175.3 (173.5–177.0)	173.1 (171.0–175.1)	0.105
Females			
Patients–hips, *n*	14–16	23–46	
Age, years	39.2 (33.7–44.7)	39.3 (35.7–42.9)	0.923
Height, cm	164.1 (160.4–167.9)	165.3 (163.6–167.0)	0.522
Males			
Patients–hips, *n*	61–80	27–54	
Age, years	37.8 (35.6–40.0)	33.6 (31.0–36.3)	0.014
Height, cm	177.5 (176.0–179.0)	179.7 (177.4–182.0)	0.093

The data are means (95% confidence intervals). FAI: anterior femoroacetabular impingement.

intra-observer reproducibility (with each criterion determined on three occasions at 3-week intervals by a single observer, AE).

2.3. Statistical analysis

The statistical analyses were performed using Excel 2007™ (Microsoft, Redmond, USA) and MedCalc™ v.11.6.1.0 (MedCalc Software, Mariakerke, Belgium). ICCs were computed using the two-way model with the same observers for all subjects, single measures, and absolute agreement. The results were described as the mean with its 95% confidence interval (95% CI) and the range (minimum–maximum values). Groups were compared using the Student *t*-test and Mann–Whitney test, with *P* values < 0.05 being considered significant.

Values in the general population of asymptomatic individuals and the population with FAI were estimated by computing a single boundary for the 95% reference interval (95% RI) [9]. The boundaries of the 95% RI in the control group were taken as the diagnostic thresholds and were assessed by application to the control and FAI groups. Youden's index was used to assess the performance of these diagnostic thresholds. Youden's index can range from 0 (no diagnostic efficacy) to 1 (perfect diagnostic efficacy). Youden's index is computed as the sum of sensitivity and specificity minus 1.

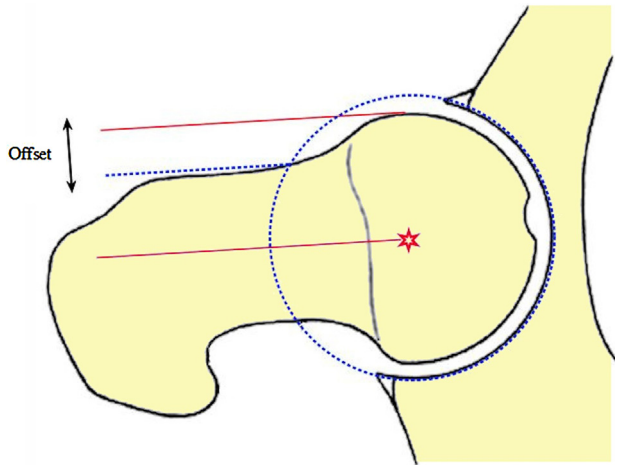

Fig. 4. Modified method for measuring antero-superiorhead-neck offset (black arrow): distance between two lines parallel to each other and to the femoral neck axis. The red line is tangent to the femoral head, and the blue line runs through the intersection between the antero-superior edge of the neck and the circular projection of the acetabular cavity (dotted blue circle).

3. Results

Inter-observer and intra-observer reproducibility was very good for all three measurements. Reproducibility was similar for the two specific measurements and femoral head diameter, validating the use of the α angle and HNO on the F45 view (Table 2).

Mean values in the controls and FAI patients were as follows: α angle, 49.3° and 73.9° (*P* < 0.0001); HNO, 7.6 mm and 2.5 mm (*P* < 0.0001); and AOR, 0.145 and 0.046 (*P* < 0.0001) (Table 3).

The α angle and AOR differed significantly between male and female controls. Normal values in male controls were α angle < 63°, HNO > 4 mm, and AOR > 0.07. Normal values in female controls were α angle < 57.5°, HNO > 5 mm, and AOR > 0.11 (Table 4).

The upper boundary for the α angle showed good diagnostic performance: thresholds of 63° in males and 58° in females had 0.91 and 0.88 sensitivity and 0.91 and 0.96 specificity, respectively. Diagnostic performance was not as good for HNO and AOR. The comparison of data from controls and FAI patients indicated that using the same HNO and AOR thresholds in males and females improved diagnostic performance, with HNO < 4.6 mm and AOR < 0.087 supporting cam-type FAI deformity (Table 5 and Fig. 5).

4. Discussion

Many radiographic projections have been used to diagnose FAI. Meyer et al. [10] evaluated the 45° and 90° Dunn's view and the cross-table lateral view, whereas Clohisy et al. [11] used the lateral frog-leg view, which Konan et al. [12] deemed inadvisable. The reproducibility and diagnostic performance of radiographs have

Table 2
Reproducibility of measurements on 192 F45 views from patients with anterior femoroacetabular impingement.

Radiographic criteria	Inter-observer reproducibility		Intra-observer reproducibility	
	ICC	95% CI	ICC	95% CI
Femoral head diameter	0.918	0.869–0.946	0.990	0.985–0.993
α angle	0.955	0.943–0.965	0.987	0.979–0.991
Head-neck offset	0.895	0.868–0.917	0.984	0.980–0.988

ICC: intra-class coefficient; 95% CI: 95% confidence interval.

Table 3
Values of the radiographic criteria in the control group and in the group with anterior femoroacetabular impingement.

	Mean	95% CI	Min	Max.	95% RI
Control group (100 radiographs)					
α angle, degrees	49.3	47.9–50.7	35	69	60.2
HNO, mm	7.6	7.2–8.0	1.7	11.8	4.6
AOR	0.145	0.138–0.153	0.032	0.219	0.087
FAI group (96 radiographs)					
α angle, degrees	73.9	72.0–75.8	53.4	96.2	57.9
HNO, mm	2.5	1.9–3.1	−4.6	9.4	7.3
AOR	0.046	0.035–0.056	−0.092	0.189	0.133

95% CI: 95% confidence interval; 95% RI: 95% reference interval; FAI: anterior femoroacetabular impingement; HNO: antero-superiorhead-neck offset; AOR: antero-superior offset ratio (HNO/femoral head diameter).

generated controversy. The 45° Dunn's view has proven valid compared to CT [13] and MRI [14], whereas the limited usefulness of antero-posterior radiographs has been emphasised [13]. The lateral frog-leg view is not accurately standardised, and its descriptions are frequently incomplete and diverging [13,15]. A Dunn-type or lateral frog-leg view with the hip in 45° of flexion seems mandatory to adequately visualise the antero-superior part of the femoral neck, most notably the portion between 1 and 2 O'clock (on the right side), where the deformity is located. These contradictory data, together with the strong potential for advantages (including rapid, accurate, and well-standardised acquisition; widespread availability; low cost; ease of interpretation; and therapeutic usefulness)

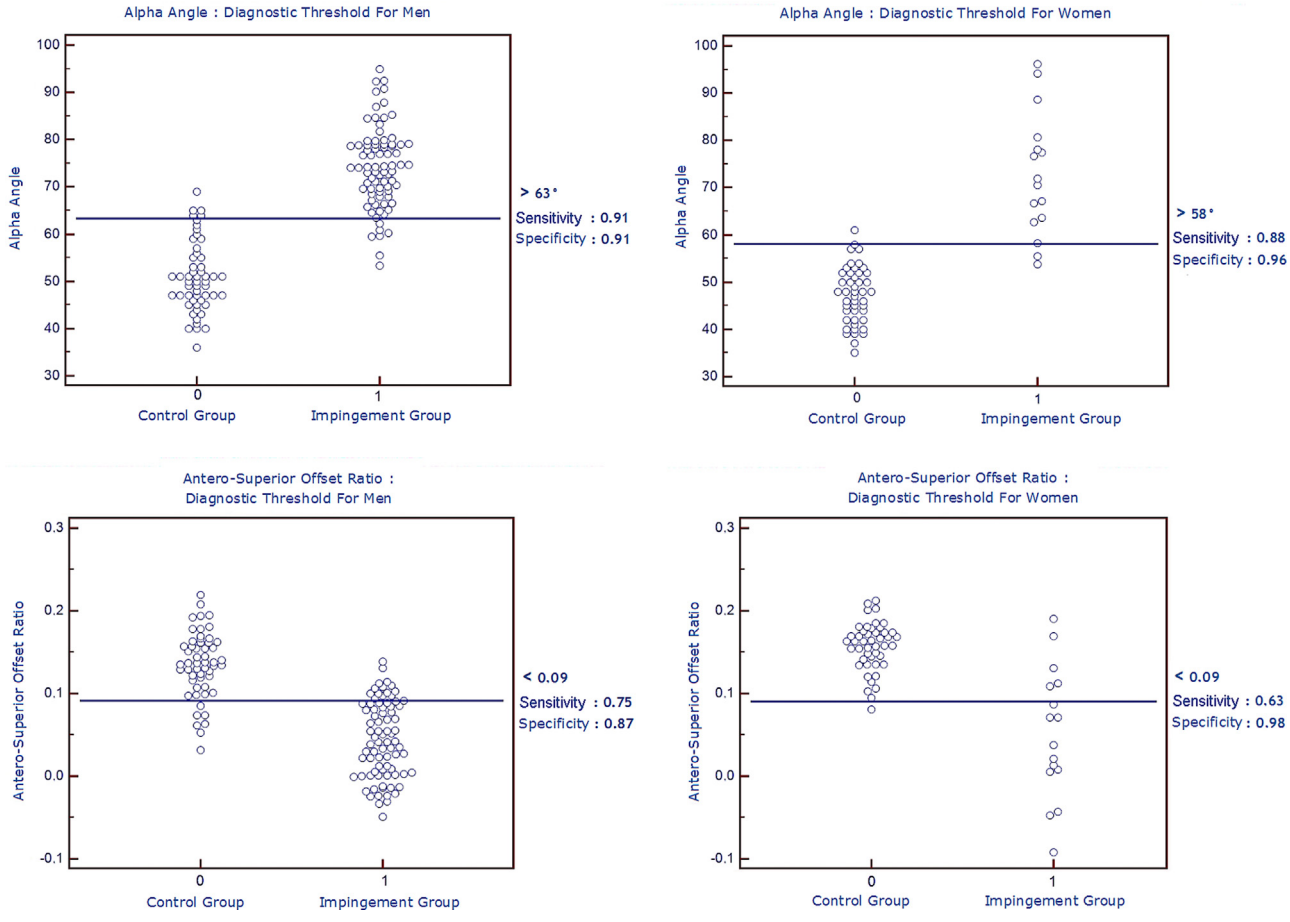

Fig. 5. Sensitivity and specificity of the optimal thresholds for the αangle and antero-superior offset ratio in males and females.

Table 4
Values of the radiographic criteria according to gender and presence of anterior femoroacetabular impingement.

	Mean	95% CI	Min.	Max.	95% RI
Male controls					
α angle, degrees	50.9	48.9–53.0	36	69	62.8
HNO, mm	7.5	6.9–8.1	1.7	11.6	4.1
AOR	0.135	0.124–0.146	0.032	0.219	0.071
Males with FAI					
α angle, degrees	74.2	72.3–76.1	53.4	94.9	59.6
HNO, mm	2.5	1.9–3.1	−2.8	7.9	6.8
AOR	0.044	0.034–0.055	−0.049	0.139	0.122
Female controls					
α angle, degrees	47.3	45.5–49.1	35	61	57.5
HNO, mm	7.7	7.3–8.2	4.2	11.8	5.0
AOR	0.157	0.148–0.166	0.081	0.212	0.110
Females with FAI					
α angle, degrees	72.6	65.7–79.5	53.8	96.2	48.0
HNO, mm	2.7	0.5–4.8	−4.6	9.4	10.1
AOR	0.053	0.010–0.095	−0.092	0.190	0.197

95% CI: 95% confidence interval; 95% RI: 95% reference interval; FAI: anterior femoroacetabular impingement; HNO: antero-superiorhead-neck offset; AOR: antero-superior offset ratio (HNO/femoral head diameter).

Table 5
Diagnostic performance of various thresholds for radiographic criteria.

	Sensitivity	Specificity	Youden's index
Females			
α > 60°[b]	0.81	0.98	0.79
α > 58°[a]	0.88	0.96	0.84
HNO < 4.6mm[b]	0.69	0.98	0.67
HNO < 5mm[a]	0.69	0.91	0.60
AOR < 0.087[b]	0.63	0.98	0.61
AOR < 0.110	0.75	0.91	0.66
Males			
α > 63°[a]	0.91	0.91	0.82
α > 60°[b]	0.95	0.85	0.80
HNO < 4.6mm[b]	0.72	0.89	0.61
HNO < 4mm[a]	0.64	0.93	0.57
AOR < 0.087[b]	0.75	0.87	0.62
AOR < 0.071[a]	0.65	0.93	0.58

HNO: antero-superiorhead-neck offset; AOR: antero-superior offset ratio (HNO/femoral head diameter).
[a] 95% Reference interval boundary for each gender.
[b] 95% Reference interval boundary for both genders pooled.

prompted us to develop and use the F45 view, whose reproducibility is confirmed by the present study.

Our study has several limitations. Differences in demographic characteristics were found: age differed in the males between the FAI and control groups, and there were few females in the FAI group (Table 1). Variations in patient posture during radiograph acquisition are inevitable, although limited by continuous training of radiologic technologists. Our use of a modified method to measure HNO may be criticisable. However, we feel this method is preferable, as the original method [8] may result in measurement difficulties in patients with FAI or after surgical correction, given the limited accuracy and relevance of the line tangent to the most anterior point of the femoral neck.

The 49.3° mean αangle in the controls was fully consistent with the value reported recently in the general population (50°) [11,16–19]. The difference between αangle values in the FAI and control groups is larger than in all previous studies except that by Nötzli et al. [7]. The mean 7.6-mm HNO and 0.145 AOR in the controls are the lowest values reported to date, except in a study of adolescents [20]. Our use of a modified method for measuring HNO explains the low values, since offset is not measured from the point of greatest femoral neck concavity but instead from a point independent from femoral neck geometry and located nearer the head-neck junction.

Distinguishing between normal and abnormal values of continuous variables is a challenging task that can be achieved by computing the 95% RI [9]. The values in our study are consistent with those reported in most of the previous publications (Table 6). The diagnostic thresholds for the α angle may seem high, although a current tendency towards reporting higher values is apparent: the initially suggested 50° threshold [7] has been widely used, but recent studies in larger samples suggest higher values of 60° [19] or 62° [18]. Even higher thresholds of about 80° have been suggested to indicate abnormal values [22,24]. Several studies [22,23,25,26] indicate that that the two genders should be considered separately when evaluating diagnostic criteria. We found this to be the case for the α angle, whereas for HNO and AOR, whose diagnostic performance was less satisfactory, a single threshold seemed appropriate, with values of < 4.6 mm for HNO and < 0.087 for AOR. Previous studies suggested higher AOR values, close to 0.150 [8,18,26]. However, reappraisals may support the use of lower values, as a recent study indicated an AOR threshold of 0.07 [27].

Table 6
Reported α angle thresholds.

Authors	Year	*n*–Pop	Imaging	Mean α angle	Upper boundary of 95% RI[a]
Nötzli et al. [7]	2002	35–A	MRI	42	50
Beaulé et al. [21]	2005	20–A	CT	44	53
Clohisy et al. [11]	2007	24–A	CTL–FL	47–44	77–67
Gosvig et al. [22]	2007	2083–OA	AP	M52–F45	Threshold indicating normal hip: M < 68 – F < 50 Threshold indicating FAI: M > 83 – F > 57
Pollard et al. [18]	2010	166–GP	CTL	47	62
Fraitzl et al. [23]	2012	339–GP	FL	M49–F46	M70–F66
Sutter et al. [19]	2012	53–A	MRI	54	60
Bixby et al. [20]	2013	132–A	CT	M52–F49	M73–F66
Agricola et al. [24]	2014	1002 (OA) + 1003 (A)	AP	–	Threshold indicating normal hip: 60 Threshold indicating FAI: 78
Laborie et al. [25]	2014	2005–GP	FL	M47–F42	M68–F56
Our study	2014	100–A	F45	49.3 (M 50.9/F 47.3)	60.2 (M 62.8–F 57.5)

n: number of individuals; Pop: source population; A: asymptomatic; OA: osteoarthritis; GP: general population; MRI: magnetic resonance imaging; CT: computed tomography; CTL: cross-table lateral radiograph; FL: frog-leg radiograph; AP: antero-posterior pelvic radiograph; F45: 45°-45°-30° frog-leg radiograph; M: males; F: females; 95% RI: 95% reference interval.
[a] Or threshold suggested by the authors.

5. Conclusion

This study validates the 45°-45°-30° frog-leg view by showing good reproducibility and ease of use in the diagnostic and therapeutic management of FAI. Numerical values of radiographic criteria differed significantly between patients with FAI and controls with normal hips, allowing us to define diagnostic threshold: α angle values > 58° in females and > 63° in males, as well as HNO < 5 mm and AOR < 0.09 in both genders, supported the presence of a high-risk anatomic configuration. Nevertheless, the diagnosis of FAI should always rest on a converging set of suggestive radiological findings and clinical symptoms.

Disclosure of interest

P. Chiron is a consultant for Zimmer, Smith &Nephew, and Sanofi; he has received royalties from Zimmer and Integra. The other authors declare no potential conflicts of interest related or unrelated to this article.

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